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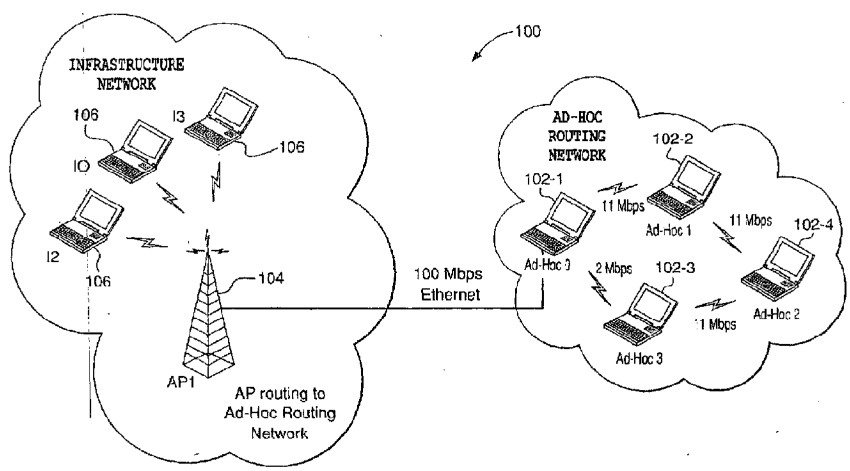
(54) Title: METHOD OF USING DATA RATES AS A ROUTING METRIC IN AD-HOC NETWORKS



(57) Abstract: A system and method for improving the manner in which data packets are delivered between nodes in an ad-hoc communications network. In particular, the system and method for achieving the best routing path for data packets being sent from a source node (102-1) to a destination node (102-4) in an ad-hoc packet-switched communications network, by enabling the source node to designate a routing path based on the data transmit rates of the nodes. The source node comprises a controller (112) that is adapted to select a routing path including at least one of a plurality of other nodes in the network via which a data packet is to be routed to the destination node based on the data transfer rates between the nodes. The controller can examine routing information indicating the data transfer rates between the nodes. The controller can examine routing information indicating the data transfer rates between nodes and select the routing path based on this information.

WO 03/051009 A1

METHOD OF USING DATA RATES AS A ROUTING METRIC IN AD-HOC NETWORKS

BACKGROUND OF THE INVENTION

Field of the Invention:

[0001] The present invention relates to a system and method for enabling a node, such as a mobile user terminal in a wireless communications network, to select a routing path including at least one other node in the network via which to route data packets to a destination node, based on the data transfer rates of those other nodes. More particularly, the present invention relates to a system and method for enabling a source node, such as a mobile use terminal that is compliant with the 802.11 standards and is operating in an 802.11 compliant ad-hoc wireless communications network, to select a routing path including other nodes in the network, such as other mobile user terminals, fixed routers and access points, via which to route data packets to a destination node, based on the 802.11 standard data transfer rates being used by those other nodes, to thus achieve maximum throughput of data between the source and destination nodes.

Description of the Related Art:

[0002] In recent years, a type of mobile communications network known as an "ad-hoc" network has been developed for use by the military. In this type of network, each user terminal (hereinafter "mobile node") is capable of operating as a base station or router for the other mobile nodes, thus eliminating the need for a fixed infrastructure of base stations. Accordingly, data packets being sent from a source mobile node to a destination mobile node are typically routed through a number of intermediate mobile nodes before reaching the destination mobile node. Details of an ad-hoc network are set forth in U.S. Patent No. 5,943,322 to Mayor, the entire content of which is incorporated herein by reference.

[0003] More sophisticated ad-hoc networks are also being developed which, in addition to enabling mobile nodes to communicate with each other as in a

conventional ad-hoc network, further enable the mobile nodes to access a fixed network and thus communicate with other types of user terminals, such as those on the public switched telephone network (PSTN) and on other networks such as the Internet. Details of these types of ad-hoc networks are described in U.S. patent application Serial No. 09/897,790 entitled "Ad Hoc Peer-to-Peer Mobile Radio Access System Interfaced to the PSTN and Cellular Networks", filed on June 29, 2001, in U.S. patent application Serial No. 09/815,157 entitled "Time Division Protocol for an Ad-Hoc, Peer-to-Peer Radio Network Having Coordinating Channel Access to Shared Parallel Data Channels with Separate Reservation Channel", filed on March 22, 2001, and in U.S. Patent Application Serial No. 09/815,164 entitled "Prioritized-Routing for an Ad-Hoc, Peer-to-Peer, Mobile Radio Access System", filed on March 22, 2001, the entire content of each of said patent applications being incorporated herein by reference.

[0004] In these types of ad-hoc networks, the algorithms that are used to determine the path of intermediate nodes via which the data packets are routed between source and destination nodes are typically based on the shortest distance between the source and destination nodes or, assuming that the data packet transport medium is wireless, the least power required to perform the routing. However, such algorithms do not necessarily produce a predictable delivery of data packets. For example, routing of data packets can be delayed due to congestion in intermediate nodes. Also, delivery failure of data packets can occur on noisy radio links between nodes.

[0005] The data rates at which nodes transmit data packets also affects the ability to route data packets between source and destination nodes. For example, the 802.11, 802.11a, and 802.11b standards support many discreet data rates that can be used by radios acting as user terminals in an ad-hoc wireless communications network to transmit data packets. A description of the 802.11 standard is found in a book by Bob O'Hara and Al Petrick entitled *IEEE 802.11 Handbook: A Designer's Companion,* IEEE, 1999, the entire contents of which being incorporated herein by reference.

[0006] Typically, radios using the 802.11 Medium Access Control (MAC) protocol attempt to establish links at the highest mutually supported data rate. A description of this process can be found in the "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications" section of the Draft 802.11 Standard, the entire contents of which being incorporated herein by reference. If transmissions at the highest mutually supported data rate are unsuccessful, the radios negotiate successively lower data rates until the transmission is successful or the lowest supported rate fails repeatedly.

[0007] As can be appreciated by one skilled in the art and as shown in Fig. 1, lower data rates yield higher effective ranges. Specifically, due to their distances apart, stations STA 1 and STA 2 can chose either the 1 Mbps rate or the 2 Mbps rate to transmit data to each other. As indicated, they are out of range to chose the 5.5 Mbps or 11 Mbps rates.

[0008] The 802.11 MAC standard also limits communication between radios to 1 hop in the ad-hoc mode, and to 2 hops in the infrastructure mode. That is, in conventional 802.11 ad-hoc networks, only peer radios that are able to communicate directly with each other are allowed to deliver data. All nodes in an infrastructure network communicate only with an Access Point (AP) as shown in Fig. 2. Furthermore, as shown in Fig. 3, in a conventional 802.11 ad-hoc network, all nodes communicate directly with each other. Hence, if one node is outside the effective range of another node, the two nodes cannot communicate.

[0009] Accordingly, in a conventional 802.11 standard network, slow links may be unavoidable because there is only 1 route to the destination, namely, directly to the peer in an ad-hoc network, and through the AP to the peer in an infrastructure network. However, routing data directly above the MAC layer in 802.11 networks may provide multiple paths to a destination node. Considering link speed with other routing metrics can allow for the lowest latency, highest bandwidth route to be chosen to a destination. For example, as shown in Fig. 4, the route consisting of nodes n0, n1, n2 and n3 can be chosen to route data from node n0 to node n3, because the available bandwidth along this path is higher than any other route. As indicated, the

route consisting of nodes n0, n4, n5 and n3 is less preferable in this example, because the 2 Mbps link between nodes n5 and n3 reduces the overall rate of the route to 2 Mbps.

[0010] This method of link-speed enhanced routing can be applied to bridge infrastructure and ad-hoc networks. However, the 802.11 standard identifies but does not specify a Distribution System Medium (DSM) to distribute traffic from an infrastructure network to other networks.

[0011] Accordingly, a need exists for a system and method for effectively and efficiently performing link-speed enhanced routing in wireless ad-hoc communications network and, in particular, in 802.11 standard wireless ad-hoc communications networks, to thus improve the manner in which data packets are delivered between nodes in the network .

SUMMARY OF THE INVENTION

[0012] An object of the present invention is to provide a system and method for improving the manner in which data packets are delivered between nodes in an ad-hoc communications network.

[0013] Another object of the present invention it to provide a system and method for achieving the most suitable routing path for data packets being sent from a source node to a destination node in an ad-hoc packet-switched communications network, such as an 802.11 ad-hoc network, by enabling the source node to designate a routing path based on the data transmit rates of the nodes, to thus maximize data throughput.

[0014] These and other objects are substantially achieved by providing a source node, such as a wireless mobile node adapted for use in a wireless communications network, which comprises a controller that is adapted to select a routing path including at least one of a plurality of other nodes in the network via which a data packet is to be routed to the destination node based on the data transfer rates between the nodes. The controller can examine routing information indicating the data transfer rates between nodes that is stored in a memory of the source node, and select the

routing path based on this information, to thus achieve maximum throughput of data between the source and destination nodes. The nodes can be fixed or mobile nodes, and one or more of the nodes can provide the source node with access to another network. The data packet can include voice data, video data and/or multimedia data. The controller of the source node is further adapted to change the selected routing path in response to a change in at least one of the respective data transfer rates between the other nodes, to thus maintain maximum throughput.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] These and other objects, advantages and novel features of the invention will be more readily appreciated from the following detailed description when read in conjunction with the accompanying drawings, in which:

[0016] Fig. 1 is a conceptual diagram illustrating an example of the relationship between the distance between two terminals in an ad-hoc wireless communications network according to 802.11 standards and the data transmission rates that are available to the two terminals based on that distance;

[0017] Fig. 2 is conceptual block diagram illustrating an example of the relationship between an access point and stations in an access point infrastructure configuration of an ad-hoc wireless communications network according to 802.11 standards;

[0018] Fig. 3 is a conceptual block diagram illustrating an example of the relationship between stations in an ad-hoc configuration in an ad-hoc wireless communications network according to 802.11 standards;

[0019] Fig. 4 is a conceptual diagram illustrating an example of the relationship of the data transfer rates between nodes in an ad-hoc wireless communications network according to 802.11 standards;

[0020] Fig. 5 is a conceptual block diagram of an example of an ad-hoc packet-switched wireless communications network employing a system and method for enabling a node, such as a mobile user terminal, in the network to route data packets

to other nodes in the network based on the data transfer rates of other nodes according to an embodiment of the present invention; and

[0021] Fig. 6 is a block diagram illustrating an example of components contained in a node employed in the network shown in Fig. 5.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] Fig. 5 is a block diagram illustrating an example of an ad-hoc packet-switched wireless communications network 100 employing an embodiment of the present invention. Specifically, the network 100 includes a an ad-hoc routing network portion including a plurality of mobile wireless user terminals 102-1 through 102-4 (referred to generally as nodes 102), and an infrastructure network portion having at least one access point 104 for providing the nodes 102 with access to the terminals 106 in the infrastructure network. In this example, AP 104 is coupled to node 102-1 by a 100 Mbps Ethernet connection. Also, although only four nodes 102-1 through 102-4 are shown, it can be understood that the ad-hoc portion of the network 100 can include any suitable number of nodes 102.

[0023] As can be appreciated by one skilled in the art, the nodes 102 are capable of communicating with each other directly, or via one or more other nodes 102 operating as a router or routers for data packets being sent between nodes 102, as described in U.S. Patent No. 5,943,322 to Mayor and in U.S. patent application Serial Nos. 09/897,790, 09/815,157 and 09/815,164, referenced above. Specifically, as shown in Fig. 6, each node 102 includes a transceiver 108 which is coupled to an antenna 110 and is capable of receiving and transmitting signals, such as packetized data signals, to and from the node 102, under the control of a controller 112. The packetized data signals can include, for example, voice, data or multimedia.

[0024] Each node 102 further includes a memory 114, such as a random access memory (RAM), that is capable of storing, among other things, routing information pertaining to itself and other nodes 102 in the network 100. The nodes 102 exchange their respective routing information, referred to as routing advertisements or routing

table information, with each other via a broadcasting mechanism periodically, for example, when a new node 102 enters the network 100, or when existing nodes 102 in the network 100 move. A node 102 will broadcast its routing table updates, and nearby nodes 102 will only receive the broadcast routing table updates if within radio frequency (RF) range of the broadcasting node 102.

[0025] Each of the nodes 102-1, 102-2 and 102-7 that receive the routing table information from node 102-2 can store all or a relevant portion of that routing table information in their respective memory 114. Typically, each node 102 will perform a pruning operation to reduce the amount of routing table information that it stores in its memory 114 as can be appreciated by one skilled in the art.

[0026] It is also noted that when a node 102 broadcasts the routing table information to its neighboring nodes 102, the node 102 can include routing table information pertaining to some or all of its neighboring nodes 102 that it has previously received from them and has stored in its memory 108. Accordingly, a node 102 receiving the broadcast routing table information from another node 102 also receives some information pertaining to the routing capabilities of the neighbors of that other node 102. For example, when node 102-1 broadcasts its routing table information, assuming that nodes 102-2 and 102-3 are within the RF range, those nodes will receive the routing table information from node 102-1 and update their routing tables accordingly. This routing table information can include information pertaining to, for example, other nodes 102 as well. Hence, nodes 102-2 and 102-3 can receive routing information pertaining to other nodes 102 via the routing table information broadcast by node 102-1. In this event, a node 102 can store in its memory 114 routing table information pertaining to nodes 102 that are several hops away.

[0027] An example of the manner in which a source node 102 can communicate data packets to a destination node 102 in accordance with an embodiment of the present invention will now be described. Specifically, the controller 112 of a source node 102 can determine the intermediate nodes 102 through which to route data packets to a destination node 102 based on the data transfer rate of the intermediate

nodes 102. The destination node 102 can be the final destination for the data packets or, in other words, the node 102 having the Internet Protocol (IP) address to which the data packets are addressed.

[0028] Alternatively, the destination node 102 can itself be the last node along a particular routing path for which the source node 102 has routing table information. In other words, the source node 102 may not have any routing information for nodes 102 that are more hops away than a particular destination node 102, in which event source node 102 will perform the operations discussed below to select the appropriate route to send the data packets to this destination node 102. The destination node 102 will in turn become a source node and perform similar operations to further route the data packets along an appropriate route to another destination node, which may or may not be the final destination to which the data packets are addressed. The process is then repeated until the data packets ultimately reach their final destination node.

[0029] The manner in which a source node, for example, node 102-1, considers potential routing paths to route data packets to a destination node, for example, node 102-n will now be described. According to an embodiment of the present invention, the source node 102-1 which is sending the data packets determines the route of intermediate nodes by which the data packets are to be sent to a destination node 102-4 based on the routing information that it has received and stored in its memory 114. This information can include, in particular, the data transfer rates between particular nodes 102. As discussed above, each node 102 can provide this information to its neighboring nodes 102 via broadcast routing table information updates, or in any other suitable manner. Accordingly, source node 102-1 can receive and store this information in its memory 114, and use this information in determining a suitable routing path for data packets.

[0030] For instance, in this example, the data rate for transmission of data packets between node 102-1 and node 102-2 is 11 Mbps. Likewise, the data rate for transmission of data packets between node 102-2 and node 102-4 is 11 Mbps. However, the data rate for transmission of data packets between node 102-1 and node 102-3 is only 11 Mbps. Hence, in order to maximize data packet throughput, node

102-1 would select the route including node 102-1, 102-2 and 102-4 to send data packets to node 102-4, which would achieve a data transfer rate of 11 Mbps. Node 102-1 would avoid selecting the route including node 102-1, 102-3 and 102-4 to send data packets to node 102-4, which would have a data transfer rate limited to 2 Mbps, which is the data transfer rate between nodes 102-1 and 102-3.

[0031] It should also be noted that a node 102 in an ad-hoc routing network may choose to lower or raise its data transfer rate according to its own criteria. Accordingly, the rate between nodes 102-1 and 102-2 may not always be 11 Mbps, but rather, may drop to 2 Mbps while the rate between nodes 102-1 and 102-3 increases to 11 Mbps. In this event, this information is provided to the nodes 102 (and nodes 106) via the routing table exchange process described above, so that a node can select the most suitable routing path based on the most up to date information.

[0032] In addition, by employing the link speed based routing algorithm at an AP 106, data packet traffic can be delivered from the infrastructure network to the ad-hoc routing network using the lowest latency and highest bandwidth path. Assuming, for example, that the node 106 labeled "I2" in Fig. 4 has a data packet destined for node 102-4 in the ad-hoc network. The two routes available are the route including I2, AP, node 102-1, node 102-2 and node 102-4, and the route including I2, AP, node 102-1, node 102-3 and node 102-4. Since this second possible route is bottlenecked by the 2 Mbps link between nodes 102-1 and 102-3, the controller of the node I2 will chose the first route as the most efficient route.

[0033] In summary, the embodiment of the invention described above considers the current data rate of 802.11 radios participating in ad-hoc routing networks when choosing routes from source to destination nodes in the network 100. Nodes temporarily using low data rates are avoided in favor of higher throughput paths when determining routes from source to destination nodes. radios in 802.11 ad-hoc routing radio networks. Through the inter-node exchange of current data rate information, such as by routing table exchange, the highest throughput paths can be chosen from sources to destination nodes. Also, the DSM can be realized by routing at the AP

(based on link speed) in an infrastructure network allowing traffic to be efficiently routed from an infrastructure network to an ad-hoc routing network.

[0034] Although only a few exemplary embodiments of the present invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims.

What is claimed is:

1. A node, adapted for use in an ad-hoc communications network, comprising:

a controller that is adapted to select a routing path including at least one of a plurality of other nodes in said network via which a data packet is to be routed to a destination node based on respective data transfer rates between said other nodes.

2. A node as claimed in claim 1, wherein:

said controller is adapted to select said routing path including a plurality of said other nodes based on said respective data transfer rates between said other nodes.

3. A node as claimed in claim 1, wherein:

said controller is further adapted to change said selected routing path in response to a change in at least one of said respective data transfer rates between said other nodes.

4. A node as claimed in claim 1, wherein:

said node includes a wireless mobile node.

5. A node as claimed in claim 1, wherein:

at least one of said other nodes includes a wireless mobile node.

6. A node as claimed in claim 1, wherein:

at least one of said other nodes includes a fixed node.

7. A node as claimed in claim 1, wherein:

at least one of said other nodes is adapted to provide said node with access to another network.

8. A node as claimed in claim 1, further comprising:

a transmitter, adapted to transmit said data packet to one of said nodes in said routing path.

9. A node as claimed in claim 1, wherein:

said data packet includes at least one of voice data, video data and multimedia data.

10. A method for controlling a node, adapted for use in an ad-hoc communications network, to select a data packet routing path, said method comprising:

determining respective data transfer rates between other nodes in said network; and

selecting a routing path including at least one of a plurality of said other nodes in the network via which a data packet is to be routed to a destination node based on said determined respective data transfer rates.

11. A method as claimed in claim 10, wherein:

said selecting selects said routing path including a plurality of said other nodes based on said respective data transfer rates between said other nodes.

12. A method as claimed in claim 10, further comprising:

changing said selected routing path in response to a change in at least one of said respective data transfer rates between said other nodes.

13. A method as claimed in claim 10, wherein:

said node includes a wireless mobile node.

14. A method as claimed in claim 1, wherein:

at least one of said other nodes includes a wireless mobile node.

15. A method as claimed in claim 1, wherein:

at least one of said other nodes includes a fixed node.

16. A method as claimed in claim 1, wherein:

at least one of said other nodes is adapted to provide said node with access to another network.

17. A method as claimed in claim 1, further comprising:

transmitting said data packet to one of said nodes in said routing path.

18. A method as claimed in claim 1, wherein:

said data packet includes at least one of voice data, video data and multimedia data.

19. A computer readable medium of instructions, adapted to control a node, which adapted for use in an ad-hoc communications network, to select a data packet routing path, said instructions comprising:

a first set of instructions, adapted to control said node to determine respective data transfer rates between other nodes in said network; and

a second set of instructions, adapted to control said node to select a routing path including at least one of a plurality of said other nodes in the network via which a data packet is to be routed to a destination node based on said determined respective data transfer rates.

20. A computer readable medium of instructions as claimed in claim 19, wherein:

said second set of instructions controls said node to select said routing path including a plurality of said other nodes based on said respective data transfer rates between said other nodes.

21. A computer readable medium of instructions as claimed in claim 19, further comprising:

a third set of instructions, adapted to control said node to change said selected routing path in response to a change in at least one of said respective data transfer rates between said other nodes.

22. A computer readable medium of instructions as claimed in claim 19, wherein:

said node includes a wireless mobile node.

23. A computer readable medium of instructions as claimed in claim 19, wherein:

at least one of said other nodes includes a wireless mobile node.

24. A computer readable medium of instructions as claimed in claim 19, wherein:

at least one of said other nodes includes a fixed node.

25. A computer readable medium of instructions as claimed in claim 19, wherein:

at least one of said other nodes is adapted to provide said node with access to another network.

26. A computer readable medium of instructions as claimed in claim 19, further comprising:

a fourth set of instructions, adapted to control said node to transmit said data packet to one of said nodes in said routing path.

27. A computer readable medium of instructions as claimed in claim 19, wherein:

said data packet includes at least one of voice data, video data and multimedia data.

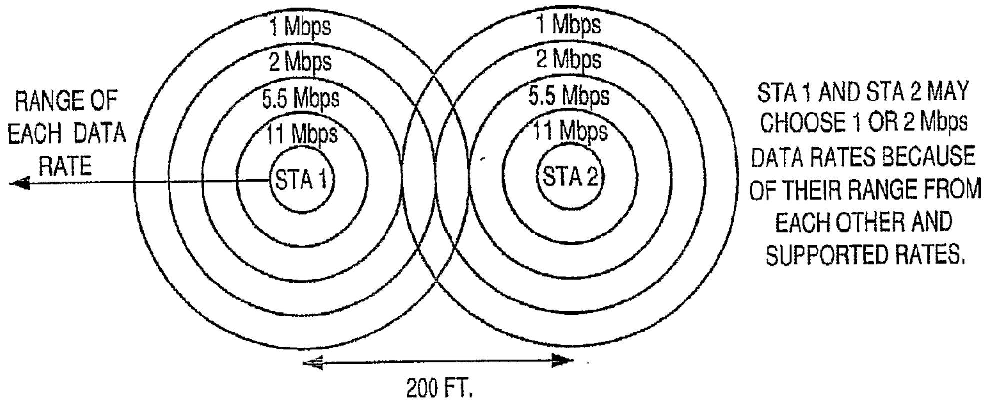

1 Mbps
2 Mbps
5.5 Mbps
11 Mbps
STA 1
STA 2
RANGE OF EACH DATA RATE
STA 1 AND STA 2 MAY CHOOSE 1 OR 2 Mbps DATA RATES BECAUSE OF THEIR RANGE FROM EACH OTHER AND SUPPORTED RATES.
200 FT.

FIG. 1

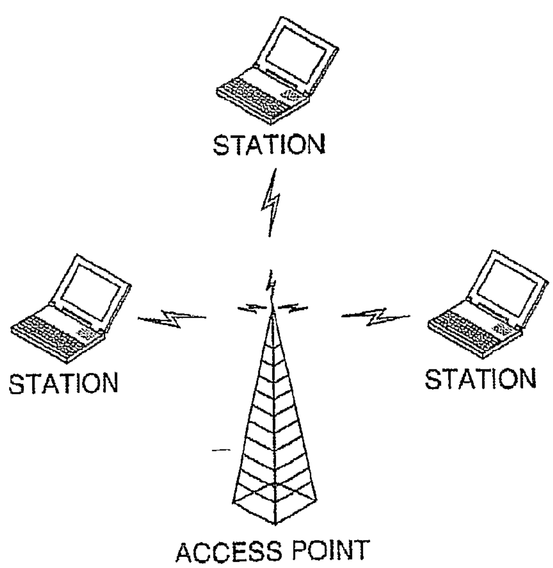

STATION
STATION
STATION
ACCESS POINT

FIG. 2

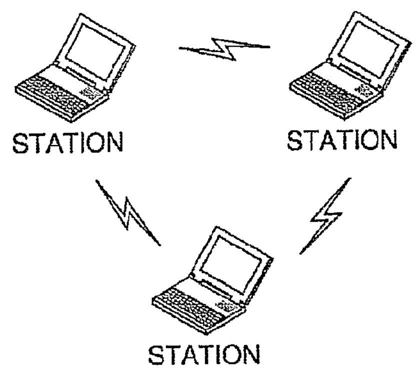

STATION
STATION
STATION

FIG. 3

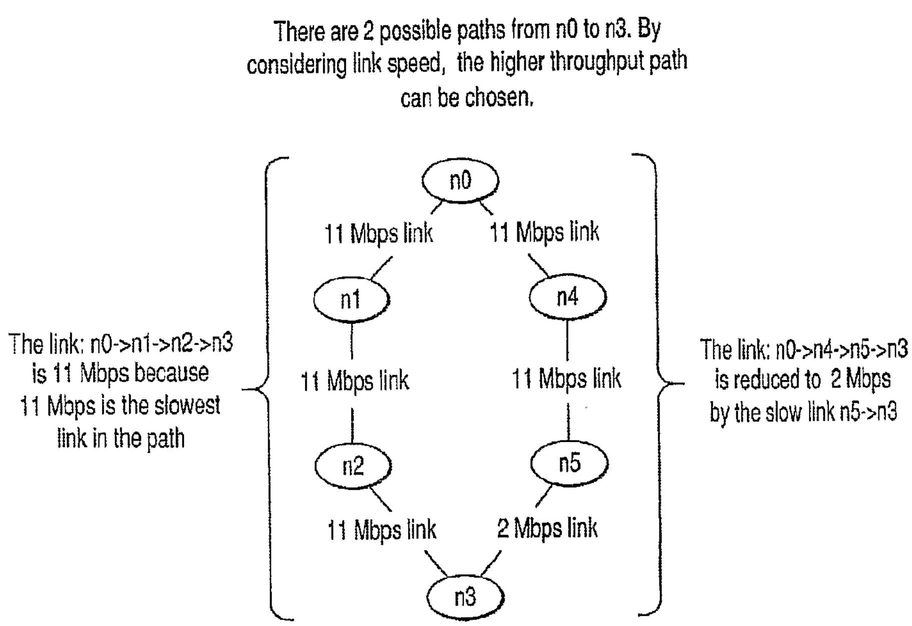

There are 2 possible paths from n0 to n3. By considering link speed, the higher throughput path can be chosen.
n0
11 Mbps link
11 Mbps link
n1
n4
The link: n0->n1->n2->n3 is 11 Mbps because 11 Mbps is the slowest link in the path
11 Mbps link
11 Mbps link
The link: n0->n4->n5->n3 is reduced to 2 Mbps by the slow link n5->n3
n2
n5
11 Mbps link
2 Mbps link
n3

FIG. 4

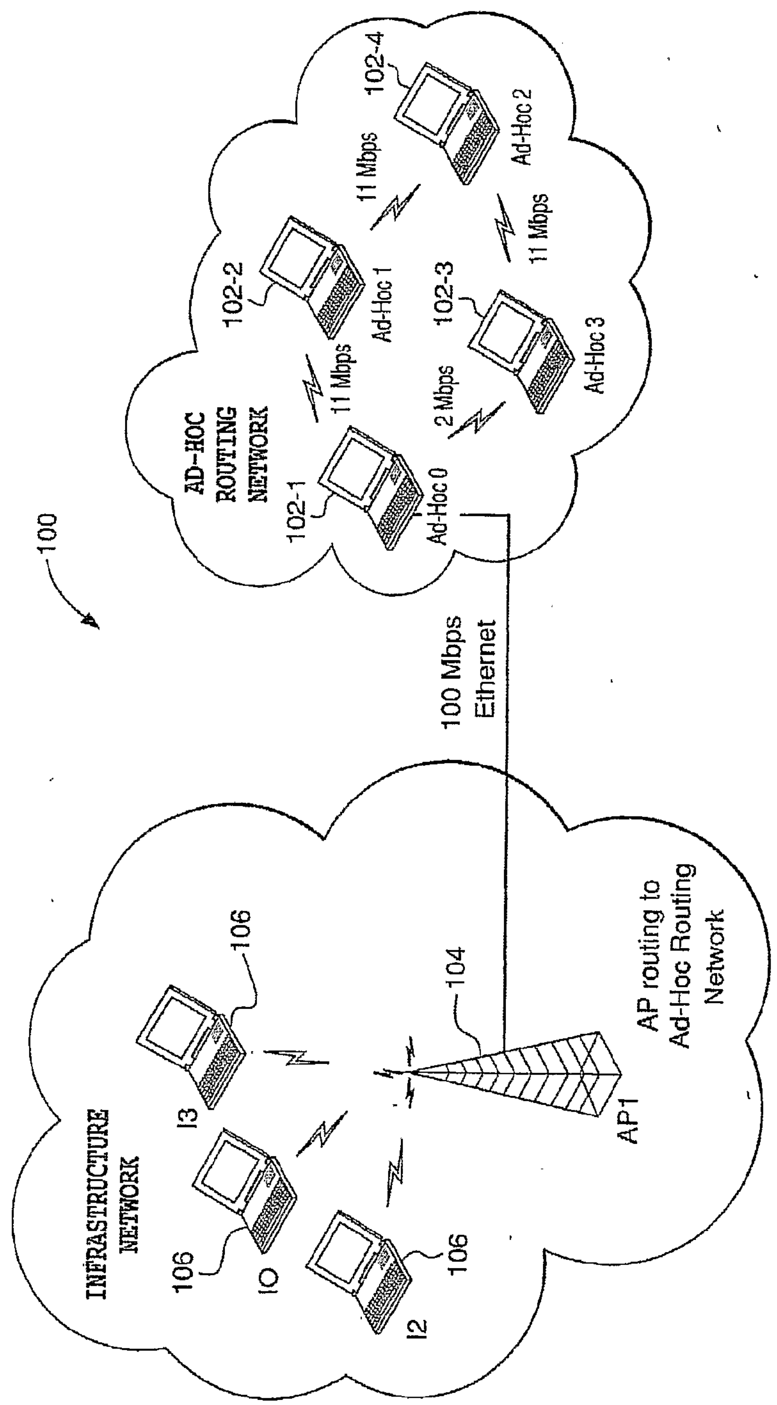

100
AD-HOC
ROUTING
NETWORK
102-1
Ad-Hoc 0
102-2
Ad-Hoc 1
102-3
Ad-Hoc 3
102-4
Ad-Hoc 2
11 Mbps
11 Mbps
11 Mbps
2 Mbps
100 Mbps
Ethernet
INFRASTRUCTURE
NETWORK
106
106
106
I0
I2
I3
104
AP1
AP routing to
Ad-Hoc Routing
Network

FIG. 5

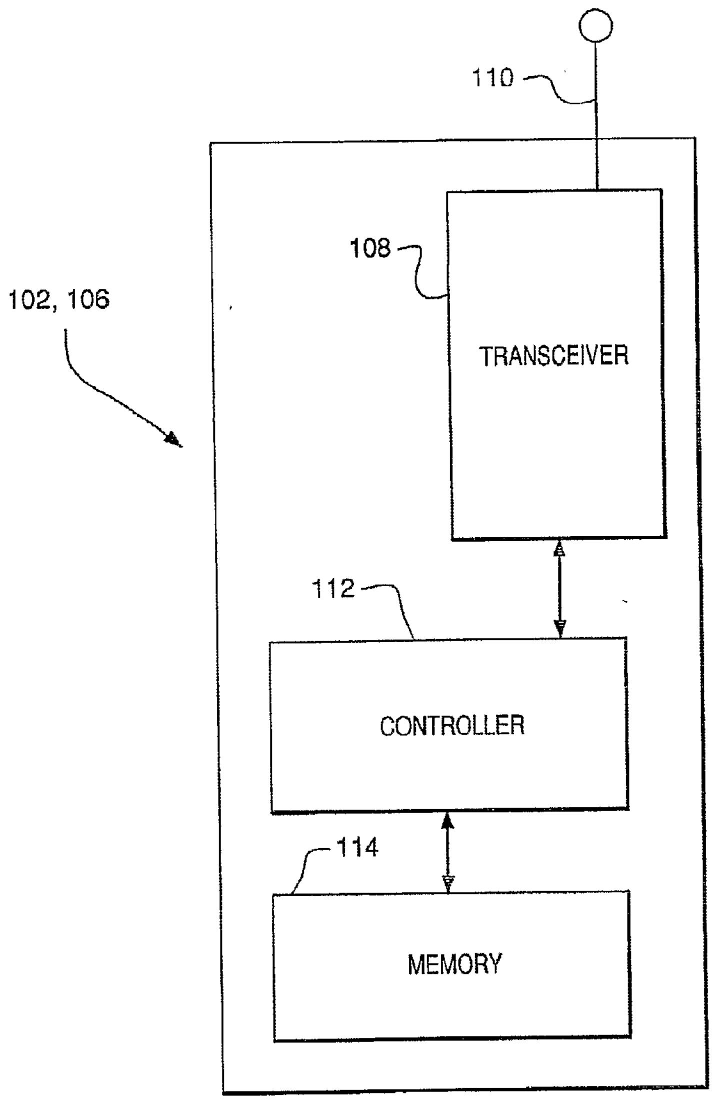


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/38970

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H04L 12/56
US CL : 370/232
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 370/232

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	CHEN et al., Shigang and NAHRSTEDT, Klara. Distributed Quality-of-Service Routing in Ad-Hoc Networks. IEEE Journal on Selected Areas in Communications, Vol. 17, No. 8, August 1999.	1-5, 8-14, 17-23, 26-27 ----------- 6-7, 15-16, 24-25
Y	US 5,572,528 A (SHUEN) 05 November 1996 (05.11.1996, Figures 2-3, column 21, lines 35-40.	6-7, 15-16, 24-25

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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